

# Multi Satellite Cooperative and Non-Cooperative Trajectory Coordination

Completed Technology Project (2017 - 2021)



## Project Introduction

The objective of this project is to develop a framework to optimize the coordination of multiple spacecraft, each with defined goals. Using this framework, optimal trajectories can be created for multiple spacecraft to optimize either common or opposing objectives. These objectives can be arbitrary, and applications to cooperative mission objectives such as rendezvous and science objectives such as planetary flyover will specifically be investigated. Optimal trajectories in non-cooperative cases (e.g. one spacecraft "chasing" another) will also be investigated because of the applicability to spacecraft impact mitigation and debris avoidance. The general optimization framework will subsequently be used to investigate autonomous cooperation of multiple spacecraft where the optimization is performed online and information is shared between the spacecraft. This includes exploring the degree of information sharing needed for multiple spacecraft to optimize mission goals such as autonomous rendezvous. Autonomous operations can relieve the bottleneck of ground communication and enable the completion of many more mission objectives. The first steps towards investigating spacecraft cooperation and non-cooperation will be using reachable sets that have been previously developed for single spacecraft. Given the reachable space (in orbit element space) of each spacecraft for a certain available delta V, the intersection point of the spaces presents an optimized rendezvous location for low delta V. This same idea can be extended to the non-cooperative pursuit/evasion case where an evading spacecraft calculates the pursuing spacecraft's reachable space and finds the farthest point on that space that it is able to reach. This limited investigation will then be generalized using the framework of differential game theory, which is essentially the "many player" equivalent of optimal control theory. The generalization will first be to the pursuit/evasion formulation of a differential game. This will allow direct comparison to the reachable set methods and is a stepping stone towards the more generalized differential game formulation that is more flexible in handling various mission goals. The general differential game framework will allow the optimization of arbitrary criteria to meet mission goals beyond what can be calculated using reachable sets and the pursuit/evasion game. This allows the calculation of optimal trajectories for multiple spacecraft to achieve specified goals. The general differential game formulation also enables the investigation of information sharing needed for successful cooperation. The implications of this project are far reaching and becoming increasingly significant. Space missions are becoming more complex, with greater reliance on successful coordination of multiple in-orbit assets in order to achieve more complex mission goals. As more ambitious missions make use of multiple spacecraft, optimizing overall coordination of the spacecraft will become more important to reducing cost and increasing chances of mission success. NASA's Asteroid Redirect Mission takes advantage of the greater flexibility by using separate robotic and human elements that will rendezvous near the Moon. Similarly, future manned Mars missions may require the rendezvous of multiple assets sent to the planet beforehand. There are also discussions



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about using groups of SmallSats to map asteroids. The coordination capabilities developed here can directly impact these missions by increasing science returns and decreasing costs. Understanding non-cooperative spacecraft trajectories is important as well, and has several applications. This applies to avoiding an actively hostile spacecraft, but also to impact mitigation between two non-communicating spacecraft/space objects that are at risk for collision. Impact mitigation is becoming increasingly important as the Earth's orbital sphere becomes more and more crowded with space debris.

## Anticipated Benefits

The implications of this project are far reaching and becoming increasingly significant. Space missions are becoming more complex, with greater reliance on successful coordination of multiple in-orbit assets in order to achieve more complex mission goals. As more ambitious missions make use of multiple spacecraft, optimizing overall coordination of the spacecraft will become more important to reducing cost and increasing chances of mission success. NASA's Asteroid Redirect Mission takes advantage of the greater flexibility by using separate robotic and human elements that will rendezvous near the Moon. Similarly, future manned Mars missions may require the rendezvous of multiple assets sent to the planet beforehand. There are also discussions about using groups of SmallSats to map asteroids. The coordination capabilities developed here can directly impact these missions by increasing science returns and decreasing costs. Understanding non-cooperative spacecraft trajectories is important as well, and has several applications. This applies to avoiding an actively hostile spacecraft, but also to impact mitigation between two non-communicating spacecraft/space objects that are at risk for collision.

## Organizational Responsibility

### Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

### Lead Organization:

University of Colorado Boulder

### Responsible Program:

Space Technology Research Grants

## Project Management

### Program Director:

Claudia M Meyer

### Program Manager:

Hung D Nguyen

### Principal Investigator:

Daniel Scheeres

### Co-Investigator:

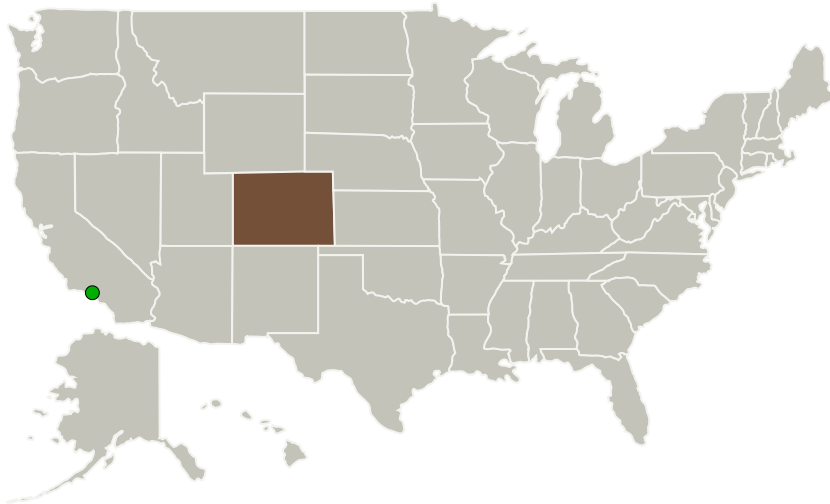
Chandrankanth Venigalla

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## Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
University of Colorado Boulder	Lead Organization	Academia	Boulder, Colorado
● Jet Propulsion Laboratory(JPL)	Supporting Organization	NASA Center	Pasadena, California

### Primary U.S. Work Locations

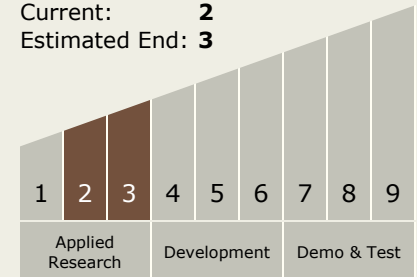
Colorado

### Project Website:

<https://www.nasa.gov/strg#.VQb6T0jJzyE>

## Technology Maturity (TRL)

Start: 2  
Current: 2  
Estimated End: 3



## Technology Areas

### Primary:

- TX12 Materials, Structures, Mechanical Systems, and Manufacturing
  - TX12.1 Materials
    - TX12.1.7 Special Materials

## Target Destinations

Earth, The Moon, Mars